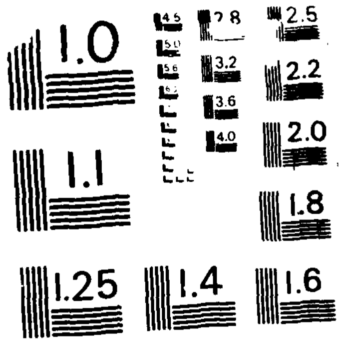
AD-A190 405 UNSTEADY FLOW IN SUPERSONIC INLET DIFFUSER(U) MICHIGAN UNIV ANN ARBOR DEPT OF AEROSPACE ENGINEERING T C ADAMSON ET AL NOV 87 AFOSR-TR-87-1887 1/1

UNCLASSIFIED AFOSR-84-0327 F/G 20/4 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 -

FINAL TECHNICAL REPORT

TO

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

UNSTEADY FLOW IN SUPERSONIC
INLET DIFFUSER

2

FINAL TECHNICAL REPORT

TO

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

UNSTEADY FLOW IN SUPERSONIC INLET DIFFUSER

Contract AFOSR 84-0327

14 August 1984 to 14 September 1987

Principal Investigators
T. C. Adamson, Jr. and A. F. Messiter
Department of Aerospace Engienering
The University of Michigan

November 1987

8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR/NA Bolling AFB, DC 20332	8b. OFFICE SYMBOL (If applicable) NA	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-84-0327

8c. ADDRESS (City, State and ZIP Code)

AFOSR/NA
Bolling AFB, DC 20332

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
61102F	2307	A4	

11. TITLE (Include Security Classification) Unsteady Flow in Supersonc Inlet Diffuser

12. PERSONAL AUTHOR(S)
Prof. Thomas C. Adamson, Jr.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Final Technical	FROM 8/14/84 TO 8/14/87	Nov. 1987	10

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
unsteady flow, self sustained oscillations, supersonic flow, inlet-diffuser

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A supersonic inlet diffuser with flow at supercritical conditions has been analyzed using a combination of analytical and numerical methods of solution. Analytical solutions for the flow variables are presented for the inviscid part of the unsteady flow field. Instantaneous displacement thickness distributions found numerically for both separated and unseparated flows allow definition of the effective wall shape for the analytical solutions. An equation describing the unsteady motion of the passage shock caused by variations in back pressure and/or wall shape has been derived. Results have been compared with those found numerically, both for inviscid and viscous flow fields; agreement is excellent in phase and good in amplitude. In example calculations, parameters are varied separately to show how they may cause shock disgorgement (engine unstart) when back pressure oscillations are impressed upon the flow. A mechanism by which shock wave oscillations may be selfsustaining has been proposed and illustrated by example. Parametric effects upon the magnitude and frequency of the self sustained oscillations and upon shock disgorgement are illustrated by numerical examples with a given inlet. Results have been

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	UNCLASSIFIED

presented in a PhD thesis, a paper at the AIAA Aerospace Sciences Meeting in 1987, and in a journal article accepted for the AIAA Journal after some revisions.

The work on inlet buzz, although not completed, has led to studies of high resolution schemes for capturing both shock and slip surface discontinuities in numerical algorithms, reported in two papers. This is still an active area of research.

1. Summary

A supersonic inlet diffuser with flow at supercritical conditions has been analyzed using a combination of analytical and numerical methods of solution. Analytical solutions for the flow variables are presented for the inviscid part of the unsteady flow field. Instantaneous displacement thickness distributions found numerically for both separated and unseparated flows allow definition of the effective wall shape for the analytical solutions. An equation describing the unsteady motion of the passage shock caused by variations in back pressure and/or wall shape has been derived. Results have been compared with those found numerically, both for inviscid and viscous flow fields; agreement is excellent in phase and good in amplitude. In example calculations , parameters are varied separately to show how they may cause shock disgorgement (engine unstart) when back pressure oscillations are impressed upon the flow. A mechanism by which shock wave oscillations may be self sustaining has been proposed and illustrated by example. Parametric effects upon the magnitude and frequency of the self sustained oscillations and upon shock disgorgement are illustrated by numerical examples with a given inlet. Results have been presented in Dr. Robert T. Biedron's PhD Thesis, a paper at the AIAA Aerospace Sciences meeting in 1987, and in a journal article accepted for the AIAA Journal after some revisions.

The work on inlet buzz, although not completed, has led to studies of high resolution schemes for capturing both shock and slip surface discontinuities in numerical algorithms, reported in two papers. This is still an active area of research.

2. Research Objectives

The principal objective of this work has been an understanding of the important physical mechanisms in unsteady supersonic flow in a supercritical inlet-diffuser. Particular emphasis was to be placed on self induced oscillations caused by interaction between the passage wave and the separated boundary layer; as time permitted, analysis of the phenomenon of inlet buzz was to be

considered. The specific objectives of this work and the order in which they were to be and were considered were listed in the Annual Technical Report for 15 August 1985 to 14 August 1986, and are repeated here as follows:

1. Using equations derived from asymptotic analysis, with instantaneous displacement thickness in separated and unseparated flow found from numerical computations, predictions of the shock wave position in unsteady flow caused by variations in diffuser exit pressure are to be made and compared with those found from numerical computations. Self-sustained oscillations are sought; i.e. cases of interest are those for which oscillation of the shock wave position, once it has begun, will continue even after the diffuser exit pressure has been returned to its original constant value, due to the interaction between the separated boundary layer and the core flow caused by the motion of the shock wave. The differential equation governing the position of the shock wave is to be analyzed in an attempt to ascertain those conditions under which self-sustained oscillations occur, or at least to identify the essential mechanisms causing this phenomenon.

2. The ideas and methods used in (1) are to be extended and applied to the phenomenon of inlet buzz. Thus, both analytical and numerical (Navier Stokes) solutions are to be sought. The numerical solution will be used to obtain typical variations with time of both the separating streamline which intersects the diffuser lip and the vortex sheet extending downstream from the triple point associated with the external shock wave. These instantaneous shapes will be used in the differential equation describing the position of the external shock wave system in an effort to identify the important mechanisms in buzz phenoma. This study is to begin upon completion of the first objective.

3. It should be noted that some support for this project was given also in the form of a mini-grant through the Southeastern Center for Electrical Engineering, Inc. A specific objective of this support, which has been completed , was a numerical solution for

unsteady viscous flow in a supersonic inlet, and the comparison of these results with experimental data.

3. Status of the Research

This work began on August 14, 1984 with a grant of $115,000. It was renewed on August 14, 1985 with a grant of $125,000 and in June 1986 with a grant of $10,940. A no cost extension was given in June 1987 in order to finish the thesis dissertation of Mr. Robert Biedron; the grant ended on September 14, 1987.

The first research objective, which involved analysis of the flow internal to a diffuser inlet and in particular the instantaneous position of the passage shock wave, required two simultaneous efforts. In the first, numerical solutions of both inviscid and viscous (described by Navier Stokes equations) unsteady flows in a two-dimensional supersonic inlet diffuser were carried out by Dr. M. S. Liou. The code for these calculations was developed with partial support from a mini-grant through the Southeastern Center for Electrical Engineering. The calculations for viscous flow were made assuming a turbulent boundary layer, in which a k-ω model for the eddy viscosity was used for closure. A paper in July 1985 by Liou, Hankey, and Mace (1st paper in list of papers in Section 4 of this report) showed comparison of results obtained with experiment in an asymmetric inlet diffuser, with excellent agreement. Indeed, Dr. Liou made extensive calculations for various geometries and flow conditions which were to be analyzed and published later. Unfortunately, the files stored in the computer of the Wright-Patterson Air Force Laboratories were destroyed due to a policy decision made at WPAFB, without early enough notification to the off base users at this University; nearly all these data were lost. Fortunately, files containing instantaneous boundary layer displacement thickness distributions as a function of time for the symmetric inlet diffuser considered in the analysis had been copied and were thus available. The cases for which these distributions were available were those in which oscillations in exit pressure were impressed upon the flow, with no self-sustained oscillations occurring. Nevertheless, the distributions for the separated flow downstream of the shock wave showed a relatively consistent dependence upon the

relative (to the shock wave) Mach number of the flow entering the shock wave whether the wave was moving upstream or downstream; hence the displacement thickness distributions downstream of the shock wave were correlated versus the relative entering flow Mach number for the unsteady flow fields considered, for use in the analytical studies.

The second effort consisted of analytical solutions of supercritical unsteady inviscid core flow in a symmetrical supersonic inlet diffuser; this work was carried out by Dr. Robert T. Biedron under the direction of Professor Adamson and formed the subject of his PhD thesis. Professor Messiter aided in the formulation of this work and in the work on the first objective. The solutions were found using asymptotic methods with flow unsteadiness caused by impressed oscillations in the exit pressure and/or in the instantaneous effective wall shape. Two general cases were considered each corresponding to a different limit process. In one, the time characteristic of the oscillations (e.g. the period) in exit pressure or wall shape is long compared to the residence time; this is the familiar slowly varying time regime in which the solution is essentially a series of steady state flow pictures, each valid for a different exit pressure and/or wall shape. The other case is that in which the period of the exit pressure or wall oscillations and the residence time are the same order. In that event, fully unsteady flow ensues with lag times being important. In an asymptotic sense, it is quite easy to identify the two cases. However, in analyzing a given inlet diffuser with only gross performance values known, it is not possible to ascertain which solution is better fitted to the physical problem; the comparison rests on the relative values of constants, both of which are the same order of magnitude. Hence, a combined solution has been formed which goes to the correct solution in the proper limit; using this combined form, a much greater range of parameter values can be covered in the numerical computation.

Solutions for the velocity, pressure, density, and temperature fields have been found. Most important for the applications considered here, is the derivation of the equation governing the instantaneous position of the shock wave when the flow is being affected by impressed oscillations at the diffuser exit and variations in wall shape downstream of the shock wave. This allows

investigations of conditions under which the passage shock wave is disgorged (engine unstart) due to pressure fluctuations and also of conditions under which self-sustained oscillations occur, perhaps with shock wave disgorgement.

Numerical example calculations have been carried out and compared with those found using numerical methods for both inviscid and viscous flows. In order to use the derived equation, one must know the effective wall shape of the inviscid core flow. In the case of inviscid flow, this is simply the physical wall shape. For comparison with viscous flow field solutions, the instantaneous displacement thickness distribution found from the numerical computations were added to the physical wall shape to give the effective wall shape. In both cases, agreement between the results found using the derived equation and those found from completely numerical solutions were good insofar as the amplitude of the shock wave motion is concerned and excellent as far as the phase is concerned.

After the comparison tests had been completed, with good results, the equation derived for the instantaneous position of the shock wave was used to investigate several unsteady flow problems in inlet diffusers. It is a first order nonlinear ordinary differential equation which must be solved numerically. Typical run times were one to three minutes of CPU time on an IBM 3090-400.

Two basic problems were investigated using example numerical computations to illustrate the effects of systematic variations of parameters. In the first, the flow was subjected to forced oscillations at the exit plane of the inlet-diffuser; completely inviscid flow was considered. In the second, self-sustained oscillations, started by impressed pressure oscillations which were then stopped no more than half a cycle later, were analyzed; in this case, the flow upstream of the shock wave was considered to be inviscid, since the displacement thickness there is relatively small compared to the channel width and does not vary much with distance, and since the flow is steady upstream of the shock wave. Downstream of the shock wave, the actual displacement thickness less its value upstream of the shock wave was used for the effective wall shape. In both sets of

calculations, a set of baseline values for each parameter was used. Then one parameter was varied with the rest being at baseline values; this allowed investigation of the relative importance of each mechanism on the unsteady motion of the shock wave.

In the first problem, in which pressure oscillations were impressed at the exit plane of the inlet diffuser, the important parameters are the initial position of the shock wave, and the amplitude and frequency of the impressed oscillation. The wall shape, that is the distribution of cross sectional area, is of course important, but is set for any diffuser and is dependent upon the displacement thickness, so this effect was not studied systematically; in the second problem its effects were analyzed in that variable wall shapes were considered. In summary, it was found that an engine unstart (shock disgorged) was more likely to occur as the initial position of the shock wave was moved upstream, the amplitude of the impressed pressure oscillations was increased and as the frequency of these oscillations was decreased. Details may be found in the paper presented and in the thesis (publications 5 and 6 in Section 4).

In the second problem a mechanism for self-sustained oscillations of the shock wave was proposed. In essence, this mechanism depends upon the variations in cross sectional flow area caused by the separated flow region downstream of the shock wave as the wave moves away from and toward its original equilibrium position; thus, an interaction phenomenon occurs. Beginning with the shock wave being downstream of its original equilibrium position (before the wave was perturbed) and moving downstream, the relative Mach number of the flow ahead of the shock increases because the increased flow area has a greater effect than the shock wave velocity; because of the increased shock strength the separation bubble and the corresponding displacement thickness grow downstream of the shock wave so that the core flow area decreases there. This, and the natural tendency of the wave to move toward its equilibrium position slow the wave motion until it stops and moves upstream, past the equilibrium point; the cross sectional flow area downstream of the shock now increases, there is a natural tendency for the shock wave to move downstream toward its equilibrium position, and the shock wave slows, stops, and reverses its motion back

downstream and the process repeats itself. When the relative Mach number of the fluid ahead of the shock wave is less than that needed for separation, the separation bubble begins to blow downstream; when conditions change again such that separation is caused by the shock, i.e. a bubble again forms immediately downstream of it, then that bubble and the one blowing downstream are rapidly joined.

Using the derived equation for the instantaneous position of the shock wave, and the displacement thickness distribution obtained from the first task it has been possible to start pressure oscillations at the diffuser exit plane, stop them after half a cycle, and still find shock oscillations; i.e. self-sustained oscillations have been found. In summary, it has been found that the self-sustained oscillations have their own frequency which is independent of the frequency of the initiating disturbance, that as the initial shock wave position is moved upstream self-sustained oscillations are larger in amplitude, and that they are smaller in amplitude as the displacement thickness decreases. The latter point suggests that such oscillations might be controlled with boundary layer removal. Details may be found in the paper and thesis, references 5 and 6 in Section 4.

Some work was done on the second objective, but due to the lack of time remaining in the grant, it could not be completed. In order to carry out computations to prove or disprove prevailing theories as to the important mechanisms in the buzz phenomenon, it is necessary to have a good approximation to the shape of the vortex sheet extending downstream from the triple point of the outer shock wave structure into the inlet, and to the shape of the dividing streamline from the inlet lip upstream to the outer shock wave. Just as numerical methods were employed to obtain the distribution of displacement thicknesses in work done for the first objective, they were to be used here to obtain the shapes mentioned above as functions of time. However, it is quite difficult to track discontinuities in velocity which are essentially in the fluid direction, as is the case in a vortex sheet and this necessitated the exploration of new methods to achieve this goal. Indeed, there is a general need for high resolution schemes for accurately capturing discontinuities, both shock and

slip surfaces, so that the work done on this project by Dr. M. S. Liou has implications more far reaching than those at issue in this problem. Dr. Liou has given a generalized formulation of the TVD scheme, reported in papers listed in references 2 and 3 in Section 4. In another somewhat related research effort he developed a Newton-upwind algorithm, reference 4 in Section 4. During this time, Dr. Liou left The University of Michigan, accepting a position at NASA Lewis Research Center. There he is continuing his work and is extending the ideas begun during the work on this project. Hence, although the work on the second objective was not completed, the work done on it was not lost; it has led to two publications and is still being actively pursued under NASA sponsorship.

4) Cumulative Chronological List of Written Publications

1. Liou, M. S., Hankey, W.L., and Mace, J. L., "Numerical Simulations of a Supercritical Inlet Flow," AIAA Paper No. 85-1214, July 1985. Also presented at meeting - see Section 6.
2. Liou, M.S., "An Efficient Method for Solving the Steady Euler Equations," AIAA Paper 86-1079, May 1986.
3. Liou, M.S., "A Generalized Formulation of High Resolution Schemes," Proceedings of First World Congress in Computational Mechanics, University of Texas-Arlington, September 1986.
4. Liou, M.S., "A Generalized Procedure for Constructing an Upwind-Based TVD Scheme, AIA," AIAA Paper 87-0355, January 1987.
5. Biedron, R. T. and Adamson, T.C., Jr., "Unsteady Flow in a Supercritical Supersonic Inlet Diffuser," AIAA Paper 87-0162, January 1987.
   Also accepted for publication in AIAA Journal.
6. Biedron, R. T., "Unsteady Flow in a Supercritical Supersonic Inlet," PhD Thesis, The University of Michigan, Ann Arbor, MI, 1987.

5. Professional Personnel Associated with Research Effort:

Professor Thomas C. Adamson, Jr.
Professor Arthur F. Messiter
Dr. M.-S. Liou
Dr. R. T. Biedron

6. Interactions

a) Paper presented at meetings, conference, seminars, etc.

1. Ref. 1: Liou, M. S., Hankey, W.L., and Mace, J. L., "Numerical Simulations of a Supercritical Inlet Flow," AIAA Paper No. 85-1214, presented at AIAA/SAE/ASME/ASEE 21st Joint Propulsion Conference, July, 1985, Monterey, California.
2. Ref. 2: Liou, M.S., "An Efficient Method for Solving the Steady Euler Equations," AIAA Paper 86-1079, presented at AIAA/ASME 4th Fluid Mechanics, Plasma Dynamics, and Lasers Conference, May 1986.
3. Ref. 3: Liou, M.S., "A Generalized Formulation of High Resolution Schemes," presented at 1st World Conference in Computational Mechanics at University of Texas-Arlington, September 1986.
4. Ref. 4: Liou, M.S., "A Generalized Procedure for Constructing an Upwind-Based TVD Scheme, AIA," AIAA Paper 87-0355, presetned at 25th Aerospace Sciences Meeting, Reno, Nevada, January 1987
5. Ref. 5: Biedron, R. T. and Adamson, T.C., Jr., "Unsteady Flow in a Supercritical Supersonic Inlet Diffuser," AIAA Paper 87-0162, presented at 25th Aerospace Sciences Meeting, Reno, Nevada, January 1987.

b) Consultative and Advisory Functions

None

7. New Discoveries, Inventions, or Patent Disclosures

None

8. Additional Statements

The investigators are grateful to AFOSR for having provided support for this work and thus for the opportunity of illustrating the benefits found using combined asymptotic and numerical methods of attack.

END
DATE
FILMED
DTIC
4/88